Energy Policy 41 (2012) 507–518

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Realising the potential of gasified biomass in the European Union—Policy challenges in moving from demonstration plants to a larger scale diffusion☆

Hans Hellsmark[a], Staffan Jacobsson[b,*]

[a] Systems Analysis, SP Technical Research Institute of Sweden, Sweden
[b] Environmental Systems Analysis, Energy and Environment, Chalmers University of Technology, Sweden

ARTICLE INFO

Article history:
Received 4 November 2010
Accepted 3 November 2011
Available online 26 November 2011

Keywords:
Gasified biomass
Policy
Biofuels

ABSTRACT

There is a great interest in synthetic fuels produced from gasified biomass. These are expected to substitute for oil, complementing first generation biofuels. While the long-term substitution potential is uncertain, it may amount to a quarter of current fuel consumption in the EU. Various design approaches for gasifying biomass have been under development for decades but the current EU focus is on nine smaller scale demonstration plants, involving three technological trajectories. The purpose of this paper is to identify policy challenges and discuss options for moving to a larger scale diffusion of gasified biomass in the EU. Such a move requires that technical and market uncertainties are handled by policy. Substantial demonstration and other risk absorption schemes will have to be developed to shift technical risks to society at large. Market uncertainties need to be reduced by a regulatory framework that ensures that markets are formed. A range of instruments for forming markets is assessed. It is argued that in order for the policy to be effective, markets for all three trajectories should be created in parallel. This leads us to suggest either dedicated quotas or a feed-in-law. Yet, both these instruments have drawbacks and a 'bridging policy' is probably necessary.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

There is currently a great interest in developing and diffusing alternative liquid fuels to oil. This is driven by concerns about security of supply, increasing prices and fear about future supply levels of oil (peak oil) as well as the climate effects of green house gas (GHG) emissions. Higher oil prices, security of supply and concerns about peak oil will primarily benefit *fossil* based alternatives, such as oil sand, natural gas to liquid (GtL) and coal to liquids (CtL), for which there are abundant feedstocks and which are often cheaper to produce than renewable alternatives (IEA, 2009).[1] These are, therefore, the first choice when there are no or weak incentives to reduce GHG emissions. However, in common for all the fossil alternatives is that they substantially increase GHG emissions (from 10 to as much as 230 per cent) as compared with conventional oil (IES JRC, 2007).[2] An increased use of fossil based alternative fuels would seriously jeopardize our ability to reduce GHG emissions by the required 80 per cent over the next four decades (Stern, 2007).

It is therefore better not to exploit fossil alternative fuels if we are to meet stringent GHG emission goals. A way forward would rather be to realize the, more limited, potential of alternative fuels from renewable energy sources, such as wood and straw.[3] With the Directives 2003/30/EC and 2009/28/EC, a substantial market has been created for renewable transportation fuels in the European Union. The binding directives stipulate that every member state needs to achieve at least 5.75 per cent biofuels by 2010 and 10 per cent by 2020 (EC, 2003, 2009). The Commission is, however, clear that the 10 per cent target is subject to the availability of the 2nd generation biofuels and that ensuring the 'commercial availability' of such fuels has high priority (EC, 2009, p. 17). With an eventual commercialization of the technology for gasifying biomass,[4] 2nd generation biofuels may be produced in

---

☆This paper was kindly funded by the Swedish Energy Agency and Gothenburg Energy. We are grateful for this support. Our gratitude is also extended to eighty-nine academics, policy makers and managers who shared their time and experience with us in interviews in Austria, Finland, Germany and Sweden as well as to one anonymous reviewer for careful and constructive reading.

* Corresponding author. Tel.: +46 10 516 58 32.
E-mail addresses: hans.hellsmark@sp.se (H. Hellsmark), staffan.jacobsson@chalmers.se (S. Jacobsson).

[1] EIA (2007), IEA (2008) and Aleklett et al. (2010) estimate that 20–26 per cent of world liquid fuels will originate from alternative fossil sources by 2030.

[2] If Carbon Capture and Storage (CCS) is applied, the emissions can be reduced to almost the level of conventional diesel and oil.

[3] Expanding the use of biomass for achieving sustainable transportation will, however, increase competition over biomass resources. The costs and benefits in using it in other applications such as heat, electricity, plastics and other type of chemicals must therefore be incorporated in any analysis of the desirability and potential of 2nd generation biofuels.

[4] In this paper we limit our analysis to synthetic biofuels produced through the thermal conversion (gasification) of forest and agricultural residues including black liquor but excluding household waste. These synthetic biofuels include FT-diesel, DME, methane and methanol. Whenever 2nd generation biofuels are mentioned in the text, these are the fuels we refer to and not, for example, 2nd generation cellulosic ethanol production. When referring to other types of biofuels we will state so specifically.

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.11.011

relatively large volumes with (a) high resource utilization to primary product (45–70 per cent), (b) no or small contributions to GHG emissions while (c) using various types of biomass feedstocks in processes that do not directly[5] compete with food production (IES JRC, 2007; Ekbom et al., 2003; Zwart et al., 2006a; RENEW, 2008; Thunman et al., 2008). For these reasons, synthetic fuels from gasification may be seen as a necessary complement to other types of biofuels, e.g. ethanol and biodiesel, in reaching the 10 per cent target, as well as to go beyond it for the EU-27 as a whole (EC, 2009).

Various design approaches for gasifying biomass have been under development for several decades. In the 1980s, gasified biomass replaced oil in some lime kilns in the paper and pulp industry and experiments were later made with electricity production. The current focus is on synthetic fuels and within the European Union there are today 9 prominent demonstration facilities in the process of being realized in Austria, Finland, Germany and Sweden. Each demonstration plant is at the heart of an alliance consisting of a wide range of firms and academic units. The firms are from the machinery, paper and pulp, petrochemical and transport equipment industries i.e. industries whose participation is essential in order to build new value chains all the way from the raw materials to the owners of transport equipment. Academic units (both Universities and Institutes) as well as engineering firms are also connected to these plants (Hellsmark, 2011).

Whereas many of these plants are well under way, none of them have yet completed the demonstration phase for the production of 2nd generation biofuels. Moreover, the step after demonstration involves a dramatic, and very costly, up-scaling of the plants to full scale semi-commercial demonstrations and, eventually, commercial plants. The various biomass gasification technologies are hence, so far, largely untried, and have not yet begun to “run down the learning curve”.

In such early phases of development of a new technology, there are generic uncertainties facing investors in terms of technology, markets and institutions (Olleros, 1986; Rosenberg, 1996; Utterback, 1994). These uncertainties also abound in the case of 2nd generation biofuels and call into question how policy, in the years to come, may continue to support the development and diffusion of various technologies to gasify biomass. They also raise questions about the realism of EU’s expectations of the time scale involved in creating a substantial supply of 2nd generation biofuels by 2020. The *purpose* of this paper is, therefore, to identify policy challenges and discuss options for moving from the current small scale pilot and demonstration plants within the European Union to a larger scale diffusion of gasified biomass in the course of the next decades.[6]

The paper is structured as follows. In the next section, we describe the technologies associated with the current demonstration projects, the main technical uncertainties associated with these and the coalitions of actors that are formed around the plants. In Section 3, we address the size of the financial risks for investors stemming from technical and market related uncertainties. Section 4 contains a discussion of different instruments, which can reduce the effects of these uncertainties for investors and shift risks to society at large. We develop a set of criteria for assessing policy instruments and apply these to a number of policy options. The final section concludes the paper.

2. Current demonstration projects, technical uncertainties and supporting alliances

This section contains an overview of the technologies that are currently being developed within the European Union for gasifying biomass, including a specification of the main sources of technical uncertainties. The search for viable alternatives is taking place along three main design trajectories in the context of nine main demonstration projects.[7] These design approaches and projects are briefly described, as are the coalitions that are associated with each of the projects.

Gasification technology rests on a set of technological capabilities associated with the thermal conversion of any carbon based fuel to a gaseous product with a usable heating value (Higman and van der Burgt, 2003).[8] Many types of feedstocks can, in principle, be used, e.g. waste, oil, coal, natural gas and biomass, and a wide range of products may be produced from the gas, e.g. FT-diesel, hydrogen, dimethylether (DME), methane (SNG) and methanol, see Fig. 1. However, not all of these alternatives are commercially available (see Higman and van der Burgt, 2003, 2008 for overviews).

Since WWII, the focus has been on fossil fuel gasification, where oil and coal dominate as feedstocks (GASIF, 2007). The current main products supplied are chemicals, ammonia as nitrogenous fertilizer and Fischer Tropsch diesel (FT-diesel). FT-diesel is a synthetic diesel with high cetane number and low sulphur content which can be blended with regular diesel for use without further engine modifications. Production of synthetic natural gas (SNG) and electricity in Integrated Gasification Combined Cycle (IGCC) are also commercial applications using fossil fuels as a feedstock (GASIF, 2004).[9]

To some extent, biomass gasification can draw upon the knowledge base of fossil fuel gasification. However, both the physical and chemical properties of biomass are distinctly different from coal, oil and natural gas. The demands on the feeding system, reactor design as well as the downstream processes are, therefore, different. Producing a 2nd generation biofuel based on biomass gasification consequently means that a set of additional competencies related to feeding, reactor design, cleaning, conditioning and catalysis of the produced gas, are required. Attempts to solve the technical challenges of biomass gasification, and associated uncertainties, are currently pursued along three trajectories (see Fig. 1). The challenges/uncertainties are marked in grey in Fig. 1 and the alliances are described in Fig. 2.

The Entrained Flow (HT-EF) trajectory draws primarily on technologies and competencies that have been developed for oil and coal gasification. It involves gasifying biomass with oxygen under high temperature and pressure. The process results in a

---

[5] Indirect competition exists for all alternatives to land use that exclude food production.

[6] There are related and highly relevant technology development projects aiming at the production of 2nd generation biofuels taking place beyond the European Union such as in the USA, Canada and China. However, these are beyond the scope of this paper.

[7] These nine projects were identified through an extensive literature review, interviews with a total of 89 industry experts and by attending a total of 14 industry conferences between 2007 and 2010. In mid 2008, it was decided on which development projects to include in the study. Since there are a lot of activities taking place in the field, other important technology development projects have emerged since then but these are not included in the current study. See Hellsmark (2011) for a longer discussion on the methodology applied. The selection procedure has meant that current UK projects that focus on gasifying waste are excluded, as was pointed out to us by a reviewer.

[8] It does, thus, not include the process of anaerobic digestion. Anaerobic digestion is a biological process for methane production and is included amongst the 1st generation production methods for renewable alternative fuels. Neither does it include 2nd generation cellulosic ethanol production.

[9] The interest in gasification has been closely linked with the availability and price of oil. A significant amount of technology development took place related to coal gasification during WW II and the apartheid regime in South Africa. Today, the main commercial interests in gasification involve substituting oil with coal and natural gas (steam reforming), and not biomass. Indeed, 30 per cent of the transportation fuels in South Africa originate from coal gasification.

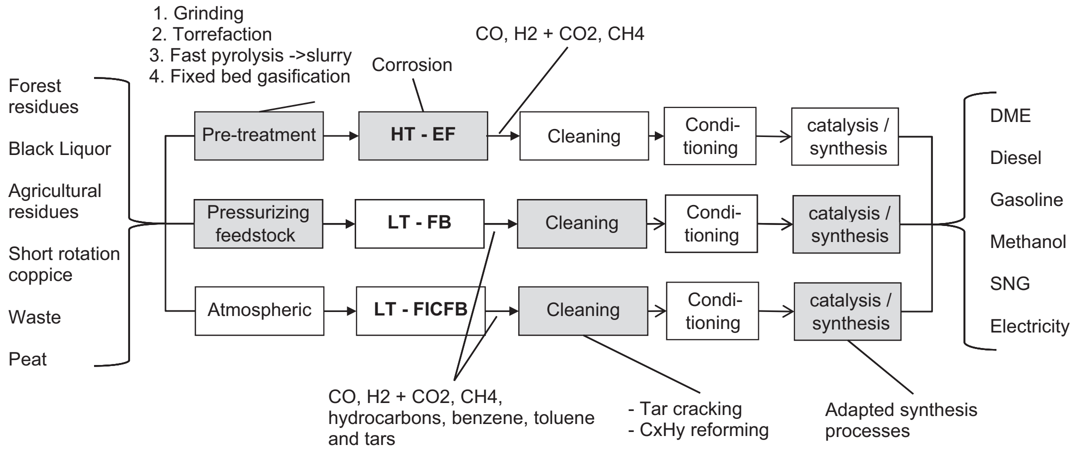

Fig. 1. The three main trajectories for biomass gasification and main technical challenges (marked in grey).
Source: Hellsmark (2011).

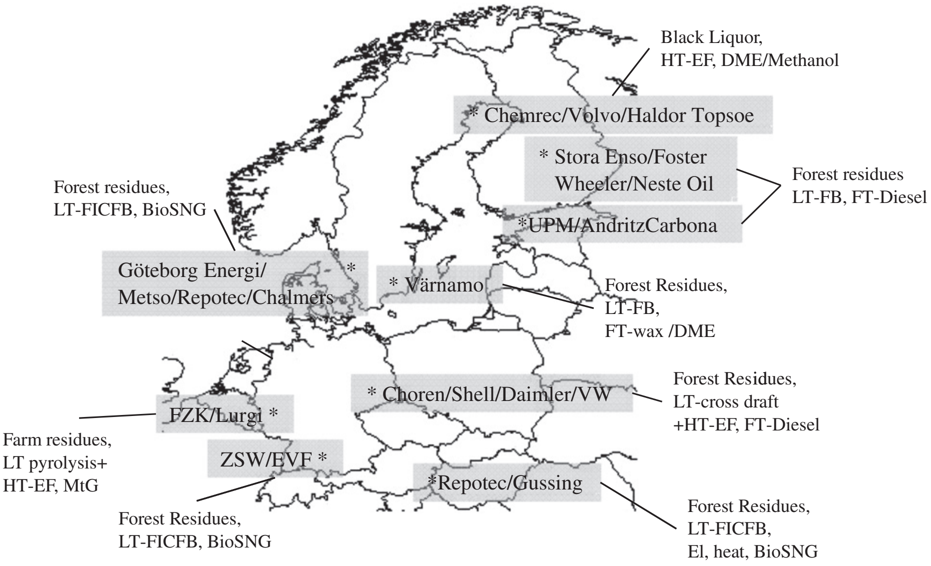
Black Liquor, HT-EF, DME/Methanol
* Chemrec/Volvo/Haldor Topsoe
* Stora Enso/Foster Wheeler/Neste Oil
Forest residues LT-FB, FT-Diesel
*UPM/AndritzCarbona
Forest residues, LT-FICFB, BioSNG
Göteborg Energi/ Metso/Repotec/Chalmers *
* Värnamo
Forest Residues, LT-FB, FT-wax /DME
* Choren/Shell/Daimler/VW
Forest Residues, LT-cross draft +HT-EF, FT-Diesel
FZK/Lurgi *
Farm residues, LT pyrolysis+ HT-EF, MtG
ZSW/EVF *
*Repotec/Gussing
Forest Residues, LT-FICFB, BioSNG
Forest Residues, LT-FICFB, El, heat, BioSNG

Fig. 2. Overview of major gasification projects in Europe pursued with the intention of addressing the above mentioned technical challenges and realising production of 2nd generation transportation fuels.
Source: Hellsmark (2011).

relatively clean gas, which after some downstream processing can be synthesized into advanced chemicals, transportation fuels or used to generate power in a combined steam and gas cycle (IGCC). The downstream processes may in the case of biomass be based on, more or less, existing coal technologies, but they still have to be demonstrated. The drawback with this route, however, is that a system for pre-treating the biomass is necessary. Such systems are not commercially available, even though experiments are being made by turning biomass into a coal-like powder through torrefaction and by making it into a slurry through the process of fast pyrolysis. Pre-treated biomass only exists in chemical pulp mills in the form of black liquor, which is suitable to be fed into the reactors. However, the HT-EF gasifiers were not originally developed to withstand the extremely corrosive character of black liquor (or corrosive biomass slurries from straw). Hence, there are currently no commercial suppliers of such gasification reactors.[10]

The two other trajectories have evolved from combustion technology into pressurized Fluidized Bed (LT-FB) and atmospheric fast internal circulating fluidized bed (LT-FICFB) gasification, see Fig. 1. In the pressurized LT-FB system, biomass reacts with a mixture of oxygen and steam. Since it is pressurized, it can be operated on a large scale, while the atmospheric process (LT-FICFB) can be operated on a smaller scale without an external oxygen supply.[11] Since fluidized bed technologies have been developed and extensively used for the combustion of biomass, they are well suited to the physical and chemical properties of biomass. Feeding biomass to the gasification reactor poses, therefore, few problems. However, these systems normally operate under atmospheric pressure and there is some, but no extensive experience with pressurized feeding systems. In addition, gas based on low temperature routes (as in these two cases) is more contaminated by tars, alkaloids, hydrocarbons, benzene, nitrogen, toluene, etc. than the gas from high temperature gasification (HT-EF) (Boerrigter et al., 2005). For the transport fuels, an *ultra clean* gas is, however, required. Currently, there is limited experience with producing such a gas with conventional cleaning methods. Producing transport fuel means, therefore, that competencies related to cleaning, conditioning and catalysis of the product gas are required, see Fig. 1.

---

[10] The use of bioslurry in a EF-reactor (GSP) developed for the corrosive character of brown coal has been successfully tested. However, the proprietary

(*footnote continued*)
owners of the GSP are not interested in developing the biomass application due to the strong demand for coal gasification (Hellsmark, 2011).

[11] When transportation fuels are produced through synthesis, biomass cannot be gasified using air as the oxidant since it contains high levels of nitrogen, which above certain levels poison the catalysts. Oxygen can instead be used together with steam as a gasification agent, but oxygen production is a costly process.

These complementary capabilities reside not within the boiler industry (mastering combustion technology) but within the chemical industry and their relevant institutes and university departments. This means that firms have to acquire the required competencies and/or operate in alliances. A feature of this technological field is, indeed, that such alliances are normally formed. These alliances also include other firms situated along the whole value chain, where a range of actors need to coordinate their investments. These include actors in the agricultural/forestry sector supplying the feedstock, the capital goods industry, suppliers of gas (including the petrochemical industry) and manufacturers of transport equipment.

These alliances each focus on a specific pilot or demonstration plant. Nine of these are found in Fig. 2. These projects target different types of biomass as feedstock, use the three types of conversion trajectories and aim for various types of end products that all can be classified as 2nd generation biofuels (FT-diesel, DME/methanol and methane). Some of the projects are in a pilot phase whereas others are in an early demonstration phase. However, none of the actors has yet completed demonstrating their technology.

In Austria, the LT-FICFB technology was developed by a Professor at TU-Vienna for small scale electricity production (Hellsmark and Jacobsson, 2009). A demonstration facility was constructed in the town of Güssing and the technology is being further developed through an inter-European network of actors towards poly-generation of BioSNG (methane), electricity and heat. The main actors in the alliance are the small engineering firms Repotec (formerly a part of the capital goods firm Austrian Energy and Environment) and CTU GMbH (for catalyst development).[12] Forming a local alliance with larger firms for the purpose of developing and diffusing the technology in Austria turned out to be difficult (Hellsmark and Jacobsson, 2009). Repotec, therefore, had to engage in intra-European alliances with a number of actors and is pursuing projects for electricity generation, poly-generation and BioSNG production in several European countries.

In Germany, three main alliances have been formed. The first two include actors in the chemical, oil, coal and automotive industries. Choren is a start-up company developing the HT-EF technology (originating in Freiberg, the coal gasification centre of Germany) and is working together with Daimler (transport equipment), VW (transport equipment) and Shell (petrochemicals) to commercialize the technology (Rudloff, 2008).[13] Forschungszentrum Karlsruhe (FZK) is at the heart of another attempt to develop the HT-EF technology together with Lurgi (capital goods), Südchemie (petrochemicals) and VW (transport equipment) (Berger, 2008). The Güssing technology is the basis for the third German alliance. The institute ZSW in Baden–Württemberg further developed the technology and is trying to take it to the market by collaborating with a local utility (EVF) and a technology consortium consisting of more than ten actors (Specht and Zuberbühler, 2007; Naab, 2008).

In the case of Sweden, there are currently three projects. The first is an attempt to form an alliance for LT-FB gasification based on the former BIGCC demonstration plant in Värnamo (Sydkraft, 1997, 2000). However, due to the lack of a capital goods supplier and other actors who could appropriate the benefits of knowledge development, it has been difficult to form an alliance of actors willing to take it to the market (Hellsmark, 2011). The necessary re-construction of the demonstration plant is, therefore, currently on hold (Swedish Energy Agency, 2007). The second alliance was initiated by Chemrec which has developed the technology for black liquor gasification. The alliance consists of Volvo (transport equipment), Preem (oil company), Total (oil company), Delphi (fuel injection) as well as other organizations in the value chain from black liquor to the use of DME vehicles in commercial traffic.

Biomass gasification is planned to be demonstrated in a third project in which the local utility Gothenburg Energy has formed an alliance with Repotec and the Finnish capital goods supplier Metso Power for building the first semi-commercial 20 MW BioSNG plant. In addition, Metso Power and Gothenburg Energy are involved in developing a new design of the LT-FICFB technology, developed in Güssing, based on a proposal by researchers at Chalmers University of Technology in Gothenburg (Gunnarsson, 2009; Thunman, 2009).

The capital good suppliers in Finland have significantly strengthened their ability to produce boilers and equipment for the pulp and paper industry over the past three decades. On the basis of a successful capital goods sector and large pulp and paper industry, two competing alliances have emerged. The first consists of Stora Enso (paper and pulp), Foster Wheeler (capital goods) and the institute VTT. They compete against UPM (paper and pulp), who has teamed up with Andritz/Carbona (capital goods) and the Chicago based Gas Technology Institute. Both alliances develop fluidized bed gasification of forest residues for the production of FT-liquids integrated in the infrastructure of the paper and pulp mills (Jokela, 2008; Palonen, 2008; Salo, 2008; Sohlström and Helin, 2008).

To conclude, the technology has been moved to an early demonstration phase and the actors have shown that they are capable of forming alliances with access to at least some of the complementary knowledge fields required. As the development of the technological field progresses towards commercial sized demonstration plants, we expect to see challenges for the private actors to coordinate simultaneous investments along the entire value chain. These coordination and development activities range from increased biomass production to technology integration in the pulp and paper industry, refineries or in other existing industries where potential synergies can be found, to the development of new infrastructure and vehicles. However, judging from the ability to form alliances hitherto, this coordination may not be a primary obstacle for the realization of the potential of gasified biomass. A more significant obstacle arguably lies in managing the substantial technical uncertainties indicated above and the even more substantial market uncertainties in up-scaling from early demonstration to semi-commercial demonstration and later to commercial scale plants. We will now address these uncertainties.

3. Uncertainties facing investors

In this section, we will elaborate on the main uncertainties facing investors, uncertainties that are central to any justification of government policy. We will begin with expanding on the uncertainties related to technology and proceed with those related to the market.

---

[12] CTU recently filed for bankruptcy http://derstandard.at/1267132355195/Guessing-CTU-Planungs-GmbH-in-Konkurs Accessed 2010-05-05.

[13] Shell left the alliance in November 2009 (Choren, 2009).

Table 1
Industry estimates of costs and time line for the major development projects in the EU.
Sources: Representatives from the different projects as well as Leible et al. (2007), RENEW (2008), Zwart (2007), Zwart et al. (2006a, 2006b), McKeough and Kurkela (2008), Atrax Energi (2002) and Thunman et al. (2008).[a]

	Pilot			**Demo**			**Pre-commercial demo**			**Commercial size**		
	Year	Size (MW)	Cost (M€)	Year	Size	Cost (M€)	Year	Size	Cost (M€)	Year	Size (Mtoe)	Cost (M€)
TU-Vienna/Repotec	1995	0.1		2002	8+1 MW	10	2013	160 GWh	75	2015 <	0.07	150
Chalmers/Metso	2008	6	1.1	2008	6 MW	1.1				2015 <	0.07	150
ZSW/EVF	2002	8	2.4	2010	10 MW	18	2013 <	10 MW		2015 <	0.07	150
Chemrec	2005	5	7	2010	5 MW/1.5 kt	28	2012/13	0.1 Mtoe	300	2015 <	0.2	400
Värnamo					18 MW	45				2015 <	0.2	400
Carbona/UPM	2005	6	10				2011/12	0.2 Mtoe	400	2015 <	0.2	500
FW/SE/Nesté				2009	12/5 MW	40	2011/12	0.1 Mtoe	400	2015 <	0.2	500
Choren	1998	1	NA	2008	45 MW/15 kt	100				2015 <	0.2	800
FZK/Lurgi	2005	0.1		2008	5 MW	4	2011	5 MW	70	2015 <	0.2	900

[a] Plans change quite frequently so the figures are very tentative.

3.1. Technical uncertainties

The nine projects described in Section 2 are all in the process of moving from the pilot stage to constructing the first demonstration units.[14] The cost of these plants ranges from 1 to 100 million Euro. However, not all of them include demonstration of the synthesis process, see Table 1.

The subsequent shift to pre-commercial demonstration plants and fully commercial plants involve dramatic up-scaling of the size and cost of the plants. For instance, for the Chemrec plant (HT-EF gasification of black liquor in Sweden) this will involve an increase in output from 1.5 ktoe in a demonstration plant that was constructed (but not taken in operation) in 2010 to 100 ktoe in a pre-commercial plant (ready by 2012–2013) and to 210 ktoe in a commercial plant to be ready to be taken into operation by 2015 (Rudberg, 2008; Domsjö, 2009; Chemrec, 2010). The investment costs would typically be between €400 and 800 million for commercial plants with a production capacity in the range of 0.2 Mtoe (Thunman et al., 2008).[15]

As pointed out in Section 2, there are substantial technical challenges, and therefore, uncertainties facing investors. Throughout the up-scaling process, uncertainties of a technical nature are likely to remain although they are expected to be smaller as the up-scaling process proceeds. On the other hand, the sums involved are much larger, so technical uncertainties still constitute a serious obstacle to investment. Conventionally, demonstration plants receive investment subsidies from governments but risk absorption schemes may also be applied, such as in the case of the Güssing plant in Austria (Hellsmark and Jacobsson, 2009). In that particular case, if the project fails, the loan will not have to be repaid. As the Austrian Research Promotion Agency (FFG) absorbs the risks, the bank does not need to add a risk premium.

Given the sums involved, any government programme has to be very large, at least set in relation to other renewable energy technologies (with the exception of off-shore wind power). In the Swedish case, for instance, a funding scheme for the demonstration and commercialization of 2nd generation biofuels and other energy technologies instituted in 2008 involves about SEK 875 million (€87 million)[16] over a period of 3–4 years (Swedish Energy Agency, 2008). This scheme represents a major increase in the availability of such funding. Through the above mentioned scheme, Chemrec has been granted SEK 500 million (€50 million) and Gothenburg Energy[17] SEK 222 million (€22 million) to complete the pre-commercial demonstration phase, see Table 1. Hence, in spite of a major increase in the funds made available, these two projects have clearly 'crowded out' other technologies.

Continuing with the case of Sweden, assuming that one plant from each of the three trajectories will be constructed in the next phase, an additional €1000 million would have to be raised. To cover, say, 20 per cent of the total investment, a demonstration funding scheme of an additional €200 million would, therefore, have to be made available. An obvious policy challenge is, thus, to devise large enough programmes that can induce investors to face the technical uncertainties in moving to the first commercial plants.

Such programmes must have a long-term commitment from policy makers in order to be effective. Currently, almost all of the alliances are constructing plants or are attempting to get their demonstration plants into operation. Table 1 indicates when the various alliances predict that their projects will pass through the different phases. The year refers to when they expect the various plants to have been constructed and not when they will be taken into operation.

Based on the history of the field, these time plans are likely to be optimistic. For the Värnamo BIGCC demonstration plant, which was built in Sweden in the 1990s, it took approximately three years after its construction before it was operating satisfactorily and an additional three years to complete the demonstration programme (Sydkraft, 1997, 2000). To produce 2nd generation biofuels from biomass gasification is a considerably more complex process than BIGCC. It may, therefore, be reasonable to assume that it will take at least three years, probably more, from when a first (and smaller) demonstration plant has been constructed until an investor is willing to commit to a (larger) pre-commercial demonstration plant.[18]

Investors would, thus, be able to decide whether to start constructing the first pre-commercial demonstration plants no earlier than 2014. It will then take three to four years to construct and demonstrate these larger plants, which means that an investment decision for the first commercial size plant cannot be taken until 2017–18. The first commercial and continuously produced 2nd generation biofuels from biomass gasification cannot, therefore, be expected to be available earlier than about 2020.

---

[14] The exception is UPM and Andriz/Carbona, who plan to go directly from pilot to semi-commercial demonstration. Their pilot plant is, therefore, seen as their demonstration plant. The reconstruction of the Värnamo plant is currently on hold but there is still hope of forming an alliance with actors willing to take some of the required investment costs.

[15] The large differences concerning investment costs in Table 1 are influenced by the large uncertainties involved but also depend on technological trajectory, end-product and the possibilities of integrating and sharing costs with existing industry infrastructure.

[16] 1 SEK is approximately 0.1 EUR.

[17] The Gothenburg Energy plant is a variant of the TU-Vienna/Repotec technology and is first on the list in Table 1 (columns 4 and 5).

[18] In the case of Repotec and Metso Power, the pre-commercial demo is the first demonstration of the production of BioSNG. The previous demonstration concerns electricity production.

Even though perhaps unrealistically, we assume that all of the projects in Table 1 are realized and at least one commercial scale plant will be built for each project. The combined production capacity of these commercial scale plants would then be approximately 1.4 Mtoe. This amounts to less than 0.5 per cent of the EU transport fuel market. Hence, 2nd generation biofuels may be available by 2020, but the volumes cannot be expected to be significant by then.

In sum, the complexity and large scale character of the technology for producing 2nd generation biofuels dictates that, from an investor's perspective, it is vital that policies involve substantial sums. The expected time scale involved in shifting from the current demonstration phase to a situation where 2nd generation biofuels may begin to have an impact on the market may also have to be adjusted, underlining the need for policy makers to have a very long-term view of this process of transformation.

3.2. *Market uncertainties*

The current EU Directive, 2009/28/EC, mandates a 10 per cent share of biofuels (by energy content) by 2020, which translates into approximately 30 Mtoe of the fuel consumption in 2008 (EC, 2009; Eurostat, 2009).[19] As argued above, only a small share may be expected to be in the form of 2nd generation biofuels from gasified biomass. Assuming that the supply of 2nd generation biofuels takes off and captures a market of, say, 30 Mtoe by 2030 it would involve building 150 plants, each supplying 0.2 Mtoe of fuel. The total value of the fuel supplied would be in the order of €15–30 billion per year and the total investment for building these hundred plants would be in the order of €60–120 billion.[20]

Looking further ahead, towards 2050, if 2nd generation biofuels captures, say, 25 per cent of what was the European market for transportation fuels in 2008 (77 Mtoe), these figures may increase to €40–80 and €150–300 billion.[21] A large scale transformation of the fuel market would, thus, entail huge market opportunities for both fuel and capital goods suppliers. Yet, there are very substantial uncertainties facing investors with respect to market formation, uncertainties that need to be handled if the potential of gasified biomass is to be realised. We will now proceed to discuss two of these; the size of the potential market and the threat from substitutes.

3.2.1. *The size of the potential market*

Estimating the potential market for a new technology is always fraught with difficulties. Unlike many other technologies, a main factor is the long-term supply capacity. For three main reasons, it is difficult to assess how much 2nd generation biofuels that can be produced through gasifying *domestic*[22] biomass resources in Europe. First, it depends on how much additional biomass can be produced and if/when lower grade biomass and waste sources can also be used for fuel production. Social and environmental aspects associated with increasing the production of biomass are difficult to assess but need to be carefully considered.[23] On the other hand, the biomass potential would be expected to increase with increased use of biomass as actors discover biomass resources to explore which previously had been unknown, underdeveloped and difficult to measure (Kåberger, 2009).

Bearing these problems in mind, the potential in Europe has been assessed in several studies. In RENEW (2008), the current (unused) potential of biomass for energy purposes in Europe was estimated at 95 Mtoe and with improved agricultural practices, primarily in the eastern parts of Europe, it could rise to approximately 172 Mtoe by 2020. In Ericsson and Nilsson (2006), the long-term European potential was estimated to approximately 410 Mtoe, but the study also included the potential of biomass resources in Ukraine and Belarus.

Second, it depends on what is perceived as a desirable allocation of the biomass potential to fuel production, as opposed to other uses of the biomass (e.g. supply of heat and power or bioplastics).[24] Third, it depends on the thermal energy efficiency, i.e. the thermal energy ratio of turning biomass into fuel. In several of the current biomass gasification projects for the production of 2nd generation fuels, FT-diesel is seen as a preferred fuel. It is, however, a complex molecule which costs more energy to synthesize than methanol, methane or DME. The exact conversion efficiencies of the different alternatives are difficult to estimate since the processes are not commercial for biomass. Nevertheless, different studies point to the possibility of converting biomass to a main fuel at an energy efficiency rate of 45–70 per cent depending on the type of processes and fuels (IES JRC, 2007; Ekbom et al., 2003; Zwart et al., 2006a; RENEW, 2008; Thunman et al., 2008).

A simple calculation has been made to illustrate the impact of these three factors on the potential to substitute fossil fuel with renewable fuel based on gasified biomass, see Table 2. The substitution potential is based on the EU-27 fuel consumption

---

[19] In 2006, the use of biofuels amounted to 5.4 Mtoe, or 1.8 per cent of the market (Eurostat, 2009).

[20] 1 Mtoe is equal to 7.3 Mbbl. To supply 30 Mtoe, or 10 per cent of current fuel consumption, and if each plant produces 0.2 Mtoe, 150 plants with a total annual production capacity of 220 Mbbl will have to be constructed. Each of these 150 plants can be expected to cost in the range of €400–800 million to construct which in total amounts to €60–120 billion (Thunman et al., 2008). The market value of 220 Mbbl equals $22.2 billion at an oil price of $100/bbl (as diesel is more valued than crude oil, the figure is likely to underestimate the value of the fuel supply). Any future oil price is very uncertain. IEA (2009) estimates the nominal price of oil to $190/bbl by 2030 in their high price scenario. The market value of the fuel would in that case be $42 billion annually. Hence, the market value of the fuel supplied would be in the range of €15–30 billion at an exchange rate of 1 USD=0.73 EUR (2010-10-04).

[21] Since the figures are highly uncertain, potential learning effects were not considered. Some learning, which would result in lower investment costs could, however, be expected for every doubling of installed cumulative capacity. In an overview by Neij (1997), large scale power plants experience, however, very little learning. In some cases, the cost may even increase with installed capacity, which was the case for nuclear and coal electricity plants. For smaller power plants, the investment cost was reduced with an average of 13 per cent each time the cumulative installed capacity was doubled (Neij, 1997). If learning will take place, one may, therefore assume that it will be at that level.

[22] If security of supply is one of the main reasons for developing biofuels, besides achieving CO_2 reduction, the calculations should be made on the basis of the availability of domestic resources.

[23] These refer to, for instance, conflicts over land use, effect on food supply, risks of monocultures etc., see e.g. Berndes and Magnusson (2006).

[24] Global system studies have concluded that the potential long-term supply of biomass is low compared to the required amount of climate neutral energy in a world aiming at limiting climate change to a two degree increase from pre-industrial levels (Azar et al., 2003). Since biomass scarcity will be a major constraint, it has further been argued that biomass is used most cost efficiently for substituting coal in electricity and heat production rather than for producing transportation fuels (Azar et al., 2003; Hansson, 2009; Grahn, 2009). Throughout this study, the advocates of biomass gasification and liquefaction projects have, however, emphasized that biomass is the only renewable feedstock for producing renewable liquid fuels and chemicals. For electricity and heat, on the other hand, there are numerous cheap, renewable alternatives available that do not include the use of biomass. These include wind, solar, hydro, geothermal, etc. for electricity production and better utilization of waste heat. Accordingly, it may still make more sense to use it for transportation fuels and chemicals.

Table 2
Substitution potential based on current fuel consumption in the EU-27 (2008).

Biomass potential (Mtoe)	95 (per cent)	170 (per cent)	410 (per cent)
Low thermal energy efficiency (45 per cent)			
Low allocation (40 per cent)	6	10	24
High allocation (60 per cent)	11	20	48
High thermal energy efficiency (70 per cent)			
Low allocation (40 per cent)	9	15	37
High allocation (60 per cent)	13	23	56

in 2008, 309 Mtoe, which is held constant (Eurostat, 2009). The biomass potential ranges from 95 to 410 Mtoe. A low and high allocation of the overall biomass potential was set at 40 and 60 per cent. The thermal energy efficiency is varied between 45 and 70 per cent (IES JRC, 2007).

This simple calculation illustrates that the potential to produce 2nd generation biofuels from biomass is highly uncertain as the substitution potential varies between 6 and 56 per cent. In terms of potential market size, the range translates to between as low as 18 and as high as 173 Mtoe. To secure investment funding, it is vital that this uncertainty is reduced. It is, therefore, imperative that advocates of 2nd generation biofuels and other chemicals work on increasing the overall biomass resources available (with due respect for social and environmental issues), secure a large share of the total (with due consideration to alternative uses of the biomass) and maximize the thermal energy efficiency.[25]

3.2.2. *Threat from substitutes*

Another source of uncertainty stem from threats from substitutes. Investments that may eventually deliver 2nd generation biofuels face a great deal of competition. They have to compete not only with the lower cost 1st generation (biodiesel, ethanol, etc.) but also with fossil based alternatives[26] and conventional fuels (DENA, 2006; IES JRC, 2007).

With respect to conventional fossil based fuels, potential investors would, in the absence of a deployment policy, face very substantial market uncertainties for both the initial nine plants and for the subsequent 100 and more plants. These uncertainties are illustrated in Fig. 3. In Fig. 3, we distinguish between three cost levels for 2nd generation fuels: 82, 140 and 165 USD/barrel. These cost levels[27] were provided by advocates of the different projects in Table 1 and Fig. 2; they are also further discussed in Hellsmark (2011).

These cost levels can be set against past, present and predicted price levels for oil. The average world oil price from 1970 to 2009 was $35.59 in 2008 dollars.[28] In the World Energy Outlook, IEA (2009) predicts the real oil price by 2030 in two main scenarios. In the first, the reference scenario, it is set at $115 per barrel and in the second, the high price scenario, it is increased to $150 per barrel (constant 2008 prices).

Fig. 3 provides a base for assessing the financial magnitude of the market uncertainties caused by unknown future oil price. It points to the hypothetic annual losses (or gains) for investors if a 10 per cent market for 2nd generation biofuels (30 Mtoe) is realized sometime in the future. Investors would lose almost $30 billion if that market were to be realised at a production cost of $165 per barrel and with an oil price at an historic average of $35 per barrel. On the other hand, with production costs of $82 per barrel of 2nd generation biofuels and with the oil price at the predicted $150 per barrel, investors would gain substantial sums.

In sum, there are substantial technical and market related uncertainties for all the necessary actors to realize the potential of 2nd generation biofuels, including those in the capital goods industry, the refinery industry and among the transport equipment manufacturers. Moreover, these uncertainties are not of a short term character but will expect to last for many years. Only very powerful and durable incentives may, therefore, be expected to induce the necessary investments, including continued coordination between investors, to take the industry into a pre-commercial demonstration phase and, eventually, form a significant supply capacity for synthetic fuels based on biomass. These incentives not only have to induce investors to face technical uncertainties for a prolonged time period but also balance the cost differentials with respect to 1st generation biofuels and manage the large market uncertainties with respect to conventional fuels. In the subsequent section, we will proceed to discuss various policy options to form a market for 2nd generation biofuels.[29]

4. Realising the opportunities of gasified biomass—an analysis of policy options

Reducing these uncertainties is the main challenge ahead for policy makers and in this section we will discuss various means of doing so effectively. We will focus on market uncertainties since investment subsidies or risk absorption schemes (managing technical uncertainties) may not alone be enough to stimulate investments (about €4 billion) even for the first set of plants (see Table 1) due to the very large market uncertainties. Yet, the technical uncertainties have to be handled as well and we will come back to these in the concluding discussion. Before we discuss the usefulness of various policy instruments for forming markets, we need, however, to specify the assessment criteria, in particular what effectiveness entails.

4.1. *Criteria for assessing policy instruments*

Effectiveness, efficiency and equity are three commonly used criteria for assessing policy options (Verbruggen, 2008; Jacobsson et al., 2009). The *effectiveness* of an instrument is assessed by its ability to meet a certain target, e.g. 10 per cent biofuels by 2020.

Efficiency, or *cost effectiveness*, often involves focusing on selecting the currently most cost-efficient technology, see for instance the 'Tradable Green Certificate Systems' in the UK, Sweden and Flanders (Jacobsson et al., 2009). There are two problems with this criterion. First, efficiency without effectiveness is meaningless; it makes sense to assess the efficiency of instruments only if they are expected to lead to the achievement of a certain target. To the extent that this requires the development and diffusion of 2nd generation biofuels, the effectiveness of

---

[25] As the industry develops, policy makers and others will have the opportunity of learning more about what levels of production may be possible and socially desirable, as well as of conflicting interests between different actors.

[26] *Alternative fossil* based fuels, with the exception of oil shale, require a much lower oil price than 2nd generation biofuels to break even. A higher oil price would, therefore, primarily induce a search for these fossil based fuels, rather than biomass based alternatives. A clear case in point is the massive interest for coal gasification in China, which attracts capital goods firms and others, at the expense of developing biomass based solutions.

[27] They refer to estimated cost levels taking into consideration the availability and cost of the biomass supply, the production method, end-product and possible integration into existing industry infrastructures.

[28] Calculated by wtgr.com Accessed 2010-05-05.

[29] In this connection, it is relevant to point out that investors, e.g. pension funds, can also invest in other types of renewables, such as wind and solar, which may make it even harder to access funding for biofuels projects. There is, indeed, a growing awareness of a "funding gap" in terms of renewables.

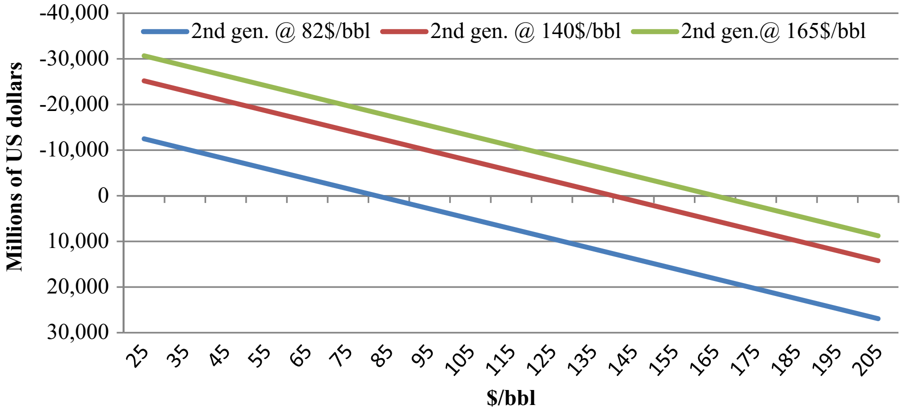

Fig. 3. A tentative assessment of financial risk for commercial size plants—annual losses or gains in realizing a 10 per cent market for 2nd generation biofuels at different oil prices ($/bbl) by 2030 (M$).

any policy instrument must be assessed, as is evident from the sections above, by its ability to influence the strategic decisions of actors to explore and develop alternative technical solutions, fill the whole value chain and coordinate actions. This process of 'putting gasified biomass on the shelf' (Sandén and Azar, 2005) has hitherto taken decades and we have still only reached the stage of smaller scale demonstration plants. Hence, unless we can convincingly argue that all instruments are likely to be equally effective, we need to scrutinize the potential impact of these on the behaviour of the capital goods industry, and other actors in the value chain, and the associated impact on technical change.

Second, minimizing costs over several decades means that we need to focus on what policy instruments can be expected to generate the lowest cost solution over the whole period, again taking technical change into account. This rests, to a large extent, on the innovative capabilities in the capital goods industry. Hence, both effectiveness and cost effectiveness rest on the ability of various instruments to influence the behaviour of the capital goods sector and its ability, in turn, to drive technical change.[30]

The third criterion is *equity* which is a crucial factor in creating social legitimacy for policies supporting new technology. Excess profits threaten legitimacy and must be avoided (e.g. European Commission, 1999; Verbruggen, 2008; Jacobsson et al., 2009; Bergek and Jacobsson, 2010).

In order to assess the effectiveness, as well as the cost-effectiveness of a policy instrument, we need to specify the goal of intervention. In broad terms, this goal is related to the need to greatly reduce the GHG emission over the next four decades. Of course, a diffusion of 2nd generation biofuels is only one element in such a change and as far as we are aware, a goal has not been specified for the diffusion of 2nd generation biofuels, neither in individual countries, nor at the EU level. However, as mentioned above, a general biofuel goal of 10 per cent of the European land transport fuel by 2020 has been set by the EU Commission, which would involve about 30 Mtoe, up from 5.5 Mtoe in 2006 (IEA, 2008, table 7.2). As we move beyond 2020, an aggressive strategy to cut emissions would involve a major increase in the supply of 2nd generation biofuels (IEA, 2008, p. 473).

What goal should then the effectiveness criterion be related to? Arguably, for the period from now until 2020, a first goal would be to move from smaller demonstration plants to having fully commercial sized plants from the different trajectories up and running. In addition, whole value chains need to be formed. Hence, a first goal is to 'put the various technologies on the shelf'. Of course, given the range of uncertainties, it is possible that some of the experiments fail and that a specific technology turns out to be unviable. A broad set of experiments ensures, though, that not all will be failures. Having the various technologies 'on the shelf' is likely to be achieved no earlier than 2020. This means that we expect it to take at least ten years to move from the current small scale demonstration plants to the first commercial size plants which can continuously produce a range of 2nd generation biofuels. As mentioned above, in terms of market share, these first plants would supply less than one per cent of the EU land transport fuel market.

In the next stage, a goal for 2030 could be set at 20 per cent biofuel, of which half could be 2nd generation biofuels. This would amount to about 30 Mtoe.[31] As mentioned above, this would involve building about 150 plants. In what follows, we will use this as a second goal.

This means that policies must be assessed with respect to their ability to meet these two goals within the specified time frame. To be effective, we will argue that several alternative technologies need to be developed. This is, of course, inherent in the first goal but also, arguably, a necessity if the second goal is to be reached.

In contrast to many other industries, such as the automobile and consumer goods industries, the different technological trajectories do not represent conventional 'competing designs', i.e. design configurations that can *fully substitute* for each other (Utterback, 1994). The applications of the technologies in the three trajectories to specific contexts are more or less constrained in their potential. For instance, feedstocks vary in their availability, e.g. the use of HT-EF with black liquor as feedstock is constrained by the number of paper and pulp mills with chemical process technology (in contrast to mechanical). Moreover, there are joint production opportunities in the paper and pulp, petrochemical and district heating industries but, of course, these are limited by the size of these industries.

The lowest cost level for producing 2nd generation biofuels in Europe based on domestic biomass resources can be expected to be found in Sweden and Finland due to large heat sinks and a paper and pulp industry in which the technologies (all three trajectories) can be integrated (Ekbom et al., 2003; McKeough and Kurkela, 2008). The potential in a European market perspective is, however, quite limited. Ekbom et al. (2003) (Table 7.1) show that the potential for FT diesel production using black liquor is about 2 Mtoe for Sweden and Finland together. This would substitute for about 20 per cent of the petrol/diesel consumption in these two countries. Even if production were to be doubled by the inclusion of fuel production in mechanical paper mills and district heating systems, meeting a goal of 30 Mtoe by 2030, and going beyond it, would certainly require that the higher cost applications of the technologies would also need to be developed and exploited.

---

[30] The criterion 'dynamic efficiency' i.e. the ability of a policy instrument(s) to foster technical change is, therefore, built into both the effectiveness and the cost effectiveness criteria.

[31] This is broadly in line with the 450 Policy Scenario in IEA (2008) if EU maintains its share of the global biofuel market.

With the long time taken to go from small demonstrations to fully commercial plants, i.e. putting the technologies 'on the shelf' and the extension of that time axis in their subsequent diffusion, *effectiveness involves creating markets for all the three trajectories applied to different contexts, which then will develop in parallel rather than sequentially, jointly gaining market shares from fossil alternatives and not from each other*. Thus, from a climate change perspective, we need to focus on the competition between fossil based (conventional and alternative) and biomass based alternatives rather than on that between the three design approaches for using biomass as a feedstock.

4.2. An analysis of policy instruments for reducing market uncertainties for investors

Having established a key criterion for assessing the effectiveness of various policy instruments, we will now proceed to discuss a number of such instruments that are either in operation or have been proposed to foster a market for 2nd generation biofuels. In the discussion, we assume that the policy instruments operate on the EU level. The instruments are a general quota for biofuel (including 1st and 2nd generations), separate quotas for 1st and 2nd generations biofuels and feed-in tariffs. Before we turn to these, we will, however, briefly mention two other instruments, tradable green certificates and inclusion of the transport sector in the European Emission Trading System (ETS).

Tradable green certificates (TGC) are an instrument that has been much favoured by the EU Commission and other actors as a deployment policy in the field of renewable power (Jacobsson et al., 2009). The core of this policy is, however, to select the currently most cost-efficient technology and only in a step-wise manner introduce more costly technologies. It is a policy instrument that deliberately abstains from creating markets for less developed and higher cost technologies (Bergek and Jacobsson, 2010). Hence, it cannot be expected to fulfil the effectiveness criterion.[32] As for the inclusion of the transport sector in the ETS, it is plain that the volatility of the price for emission permits and the highly uncertain future of the size of the cap create very large uncertainties for investors who have to estimate income streams over two or more decades. Hence, in terms of Fig. 3, the market uncertainty is very high indeed, which strongly discourages investments.

A *quota for biofuels* is currently operating in e.g. Germany. A general quota induces, however, an expansion of the least cost options first, i.e. 1st generation biofuels. Whereas the desirability of 1st generation biofuels is questionable (in terms of both its ability to reduce emissions and its use of arable land), the potential is large, especially if we consider import opportunities from Latin America and Africa. A general quota would, therefore, not be a strong inducement mechanism for firms to invest in upscaling and further developing 2nd generation biofuels.[33]

To stimulate such development, the European Commission has decided that the "… contribution made by biofuels produced from waste, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered twice that made by other biofuels" (EC, 2009, Article 21:2). In addition, the EC proposes that when Member States design their support systems they may give " … additional benefits to … biofuels made from waste, residues, non-food cellulosic material, ligno–cellulosic material and algae, as well as non-irrigated plants grown in arid areas to fight desertification … " (EC, 2009, p. 26). Hence, the Commission recognizes that 2nd generation biofuels will be considerably more expensive than the 1st generation and, thus, need additional support in order to develop.

A double counting would provide an added incentive to investors in 2nd generation biofuels that better reflect their performance in terms of CO_2 emissions. Market uncertainty remains high, however, and is magnified by the interdependency with the price of conventional fuel. Assuming that both 1st and 2nd generation biofuels are blended into diesel, the competitiveness of 2nd generation vis-à-vis 1st generation will depend on the price of conventional fuel. If that price increases, 1st generation biofuels gains a competitive edge simply since it, in terms of volume, replaces about twice as much diesel as the 2nd generation biofuel (Choren, 2007). Potential investors, thus, have to consider the future prices (over decades) of not only 1st and 2nd generation biofuels but also of conventional fuel. This adds, of course uncertainty to any investment analysis.

The effectiveness criterion, thus, excludes not only TGCs and CO_2 trade but, arguably, also a general quota. At best, a double counting of 2nd generation biofuels may be expected to induce a sequential development of the three technological trajectories, starting with the lowest cost alternative.

A separate 2*nd generation biofuels blending quota* would alleviate the problem of interdependency with the price of conventional fuel and take away the market uncertainty with respect to 1st generation biofuels. As and when the first larger plants have been taken into operation, a predetermined quota could be applied. In order to stimulate a supply capacity in the Nordic countries, a unified EU blending quota for 2nd generation biofuels may have to be coupled to trading opportunities, i.e. an export from Sweden and Finland to other countries (as is specified in Directive 2009/28/EC). Integrating the Nordic and German markets may, however, lead to equity problems. As shown in Section 3, the estimated cost levels of 2nd generation biofuels differ a great deal, to the advantage of Swedish and Finnish suppliers. With an integration of the markets, price levels would be expected to be equalised, with potential huge excess profits gained by the Nordic suppliers.[34]

An additional problem with a quota is the very substantial information requirements for a central planner in setting the quota, both its initial level and its escalation. Basically, today, nobody can with certainty say when the first commercial plant will be operational. It is even more difficult to judge how quickly the supply capacity in the capital goods industry can grow—it depends not only on the strategic choice of a number of capital goods firms but also on the access to specialised skills in a range of areas, including gasification and catalysis. A recurrent theme in interviews with capital goods suppliers and other firms was the lack of specialised competencies in the field.

---

[32] For a discussion of this point with respect to renewable power technologies, see Jacobsson et al. (2009). In that paper, there is also a lengthy discussion on the equity criterion and TGCs fail also on that account.

[33] The EU Directive states that biofuels originating from plants constructed after January 2018 must reduce CO_2 emissions with an equivalent of 60 per cent (EC, 2009). The Directive may reduce the supply of 1st generation biofuels and, hence, open up for 2nd generation biofuels somewhat.

(*footnote continued*)

[34] A (less likely) risk is that the Nordic suppliers would expand so rapidly that they could fill the whole German quota and out-compete emerging German competitors. A low quota would, therefore, lead to market uncertainty in the sense that a supplier of a higher cost alternative would always face an uncertainty with respect to whether there will be a market or not. This may lead to a sequential development and jeopardize the effectiveness criterion. Setting a relatively high quota would reduce this risk, but at the expense of high consumer costs (equity).

Feed-in with cost covering payment that differs between technologies (and contexts of application) is a well proven regulatory framework to stimulate the diffusion and further development of a range of technologies in parallel, i.e. a feed-in tariff is expected to score high on the effectiveness criterion. Just as double counting in a quota system, a feed-in tariff may stimulate more expensive, but higher performing, alternatives through setting higher prices. In principle, excess profits may be avoided by a careful price setting routine. Such prices, which are normally set for a period of 15–20 years, would, however, need to be adjusted for fluctuating feedstock prices.

However, there are two major problems with this instrument, at least at this stage. First, effectiveness necessitates that one tariff is set for each technological trajectory (and specific context). It is not, however, possible to calculate costs with the required precision without experience with full size commercial plants. Second, there is not, as yet, competition in the capital goods sector within each trajectory which means that setting a feed-in price would involve negotiations between government and monopolistic suppliers with access to superior information. This opens up for problems with respect to the equity criterion.[35]

A dedicated quota for 2nd generation biofuels appears to be a more attractive option as a price does not need to be set for 15–20 years but may evolve as experience is gained. Yet, as explained above, there are very considerable information problems for a central authority to set a quota over a longer period of time. Moreover, it remains doubtful if a promise by current politicians of a future quota would be enough to convince firms that a market will materialise with prices that will cover costs.

In sum, none of the currently discussed policy options come out as a strong candidate, at least not at this stage of development of the industry. Tradable green certificates, inclusion of the transport sector in the ETS and a general biofuel quota would be expected to fail on the effectiveness criterion. Double counting 2nd generation biofuels would, at best, lead to a sequential development of the three technological trajectories and, hence, fail on the effectiveness criterion too (but less so than the prior alternatives). A dedicated quota for 2nd generation biofuels would, if high enough, promote a broad development of gasified biomass but setting the quota level is currently fraught with extreme difficulties. Equity issues would also arise. Finally, problems with information access (and equity issues) may rule out a feed-in law.

An option would be to implement a ‘bridging policy’ that reduces the information needs among policy makers while taking away the market uncertainties for the first set of plants. One such alternative would be to implement plant-specific tax exemptions (increasing the price competitiveness of 2nd generation biofuels) coupled to guaranteed market and off-take price from public sector customer or, possibly, traders or petrochemical firms. Such a price would, in effect, be a miniaturized plant specific feed-in law. The market uncertainty (in terms of relative price level vis-à-vis conventional fuel) is then absorbed by the customer but the tax exemption would reduce the size of the potential losses. At the same time, as argued above, some of the technical risks would need to be absorbed by society at large. This temporary construction would take the capital goods industry through to the stage where the first commercial sized plants are built, reducing the technical uncertainties and completing the respective value chains.[36] It would also give the added benefit of generating a pool of experience and competencies on which a longer term policy can be based on, be it a dedicated quota for 2nd generation biofuels or a feed-in policy.

5. Concluding discussion

For close on three decades, work has been undertaken to develop the technology to gasify biomass, initially aiming for oil replacement in paper and pulp mills and for electricity production. More recently, the focus has shifted to supplying 2nd generation biofuels which are expected to become a major substitute to conventional fuels and 1st generation biofuels, contributing to a reduction in the emission of GHG while increasing security of supply. The *purpose* of this paper was to identify policy challenges and discuss options for moving from the current small scale pilot and demonstration plants in the European Union to a larger scale diffusion of gasified biomass and, thus, contribute to the debate on how policy may support the diffusion of this substitute to fossil based alternatives.

In the EU, three main technological trajectories are being explored to gasify biomass. Nine alliances of firms, institutes and universities centre on their own demonstration plant in which one of these trajectories is applied to a specific context. These plants use different production processes, different feedstocks (e.g. black liquor, straw, forest thinning, etc.) and supply different types of 2nd generation biofuels (DME/Methanol, Fischer Tropsch diesel and Methane). For these alliances, the challenge is to finish building the demonstration plants, to radically upscale them, and to supply 2nd generation biofuels from the first commercial sized plants by about 2020.

It is, however, not until subsequent plants are built that 2nd generation biofuels may make significant inroads into the market and expectations that this will take place before 2020 are probably too optimistic. As with other large scale technological transformations, the time axis extends into many decades. The longer term (2030–2050) market potential for both capital goods and fuel is, however, probably very large, although very uncertain. This potential rests on the ability to secure an enlarged supply of biomass, to ensure the allocation of a substantial share to the production of 2nd generation biofuels and to reach a high efficiency in transforming that biomass to fuel. Hence, the potential market is large but distant and uncertain.

These features meet potential investors throughout the whole value chain, from agriculture to transport equipment. Uncertainties in terms of the regulatory framework governing the outcome of investments abound, of course. This needs to be recognized by policy makers who, in turn, have to demonstrate a long-term commitment to the field, minimizing regulatory uncertainties, and securing that industry continues to develop the technology in all its aspects.

From an investor’s perspective, a commitment to 2nd generation biofuels involves facing a number of technical uncertainties that can only be reduced through building demonstration plants. Moving towards commercial scale plants involves, however, a dramatic upscaling and an associated increase in costs. As the Swedish case demonstrates, the sums involved are so large that current demonstration programmes, or schemes for risk absorption, need to be significantly enlarged in order to ensure that plants in all three trajectories, using different feed-stocks and supplying different 2nd generation fuels, are upscaled without any crowding out of other technologies that require support.

---

[35] The exception may be smaller scale plants in the ‘fast internal circulating fluidized bed gasification trajectory’ supplying SNG. A feed-in tariff could be linked to deliveries of SNG to gas grids. A supplier industry, e.g. EON, is now being formed that interacts with actual and potential customers in Austria, Germany and Sweden.

[36] This refers, in particular, to the supply of bioslurries and torrefied biomass (HT-EF trajectory), to downstream in the SNG value chain, e.g. truck engines and to infrastructure for using DME.

It may well be argued that such large scale demonstration plants should be mainly funded at the EU leveldeveloping technology that is to satisfy quotas set by the Commission and generating benefits for the whole of EU. Indeed, as all projects progress, they will depend on inter-European alliances since no country has a complete range of firms with the complementary capabilities necessary for taking the technology from pilot scale to commercial scale plants. The industry is, thus, likely to evolve into a European and not a national one. It is, therefore, unrealistic that local or national governments should be the main funders of costly and risky large scale demonstrations.

Demonstration programmes that absorb technical uncertainties need to be supplemented by policies that ensure that markets are formed. Forming such initial markets are critical for the evolution of new industries as they provide an income stream for investors and have a strong bearing on the further development of the technology. Market formation programmes are also critical due to large uncertainties caused by the unknown future prices for conventional fuel.

There is an abundance of different public policy instruments to form markets and assessing the usefulness of each of them requires that clear criteria are developed. The effectiveness of an instrument is assessed by its ability to meet a certain target, whereas efficiency, or cost effectiveness, refers to meeting this target at lowest cost. As efficiency is meaningless without effectiveness, the latter takes priority. Equity is the third criterion.

Discussing the effectiveness of an instrument requires that a goal is specified. We suggested that an EU goal for 2030 could be set at 20 per cent biofuels, out of which half could be 2nd generation. This would amount to about 30 Mtoe, involving about 150 plants. Subsequently, the market share may be increased to, perhaps, 25 per cent. This would require not only a maximum deployment of the different technologies (incorporated in this study) in the Nordic countries (using local heat sinks and joint production opportunities in the paper and pulp industry) but also the higher cost alternatives developed in Germany. Reaching this goal, thus, necessitates the coexistence of a range of technologies applied to different contexts and with quite different cost levels. With the inherently long time axis in moving towards the first commercial scale plants, and the subsequent multiplication of these, effectiveness therefore *involves creating markets for all three trajectories applied to a range of contexts* which then will develop in parallel, rather than in sequence.

Most of the currently discussed policy instruments fail on this criterion. This refers to tradable green certificates, inclusion of the transport sector in the ETS and a general biofuel quota. Double counting 2nd generation biofuels would be expected to fail on the effectiveness criterion too, but less so. A dedicated quota for 2nd generation biofuels would, if high enough, promote a broad development of gasified biomass but setting the quota level is currently fraught with extreme difficulties in terms of information access for policy makers. Equity issues would also arise. These problems may also rule out a feed-in law.

A way forward is a ‘bridging policy’ that takes away market uncertainties for the first plants whilst reducing the information needs among policy makers. Such a bridge could be built by implementing plant-specific tax exemptions coupled to guaranteed market and off-take price. The market uncertainty is absorbed by the customer but the tax exemption would reduce the size of the potential losses. This bridge would (a) ensure a market; (b) demonstrate a strong commitment to the technology; (c) take the capital goods industry through to the stage where the first commercial sized plants are built, reducing the technical uncertainties and populating the respective value chains; (d) generate a pool of experience and competencies on which a longer term policy can be based on. Whereas we argued above that the EU should fund the bulk of the demonstration programmes, the tax exemptions and the guaranteed market/off take price may be set at the national levels in order to demonstrate commitment from local actors, including policy makers, thereby strengthening the alliances.[37]

References

Aleklett, K., Höök, M., Jakobsson, K., Lardelli, M., Snowden, S., Söderbergh, B., 2010. The peak of the oil age—analyzing the world oil production reference scenario in world energy outlook 2008. Energy Policy 38, 1398–1414.

Energi, Atrax, 2002. The Bio-DME Project. Report to Swedish National Energy Administration. Atrax Energi.

Azar, C., Lindgren, K., Andersson, B.A., 2003. Global energy scenarios meeting stringent CO_2 constraints—cost-effective fuel choices in the transportation sector. Energy Policy 31, 961–976.

Bergek, A., Jacobsson, S., 2010. Are tradable green certificates a cost-efficient policy driving technical change or a rent-generating machine? lessons from Sweden 2003–2008. Energy Policy 38, 1255–1271.

Berger, U., 2008. Interview with Ulrich Berger, Lurgi, 23 January, Frankfurt.

Berndes, G., Magnusson, L., 2006. The future of bioenergy in Sweden—background and summary of outstanding issues. ER 2006, 30 Swedish Energy Agency, Eskilstuna.

Boerrigter, H., van Paasen, S.V.B., Bergman, P.C.A., Könemann, J.W., Emmen, R., Wijnands, A., 2005. ”OLGA” Tar Removal Technology. Energy Research Centre of the Netherlands, Petten.

Chemrec, 2010. Press Release: World’s first BioDME Renewable Motor Fuels Plant Inaugurated in Sweden. 2010-09-09. Stockholm, Sweden.

Choren, 2007. Suggestion Presented on Slideshow: CHOREN Stellungnahme Förderpolitik Biokraftstoffe_2007 12 engl 01, provided by Mattias Rudloff at Choren, Freiberg.

Choren, 2009. Press Release: Change in CHOREN’s Ownership Structure and Capital Increase. 2009-11-05. Freiberg, Germany.

DENA, 2006. Biomass to Liquids—Implementation Report. Deutsche Energie-Agentur GmbH, Berlin.

Domsjö, 2009. Pressmeddelande 2009-09-28: 500 miljoner kronor i investeringsstöd till biodrivmedels-projekt vid Domsjö Fabriker Domsjö Fabriker, Örnsköldsvik.

EC, 2003. Directive 2003/30/EC of the European Parliament and the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. The European Parliament and the Council of the European Union, Brussels.

EC, 2009. Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. The European Parliament and of the Council, Brussels.

EIA, 2007. Annual Energy Outlook 2007. Energy Information Administration, Washington.

Ekbom, T., Lindblom, M., Berglin, N., Ahlvik, P., 2003. Technical and Commercial Feasibility Study of Black Liquor Gasification with Methanol/DME Production as Motor Fuels for Automotive Uses—BLGMF. Nykomb Synergetics AB, Stockholm.

Ericsson, K., Nilsson, L.J., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass and Bioenergy 30, 1–15.

Eurostat, 2009. Energy statistics, 2009-11-03 ed.. European Commission.

European Commission, 1999. Electricity from Renewable Energy Sources and the Internal Electricity market, Commission Working Paper, SEC (99) 470, 13 April.

GASIF, 2004. Gasification World Survey Results. U.S Department of Energy National Energy Technology Laboratory.

GASIF, 2007. Gasification World Survey Results. U.S Department of Energy National Energy Technology Laboratory.

Grahn, M., 2009. Cost-effective Fuel and Technology Choices in the Transportation Sector in a Future Carbon Constrained World: Results from the Global Energy Transition (GET) model. Doctoral Thesis, Department of Energy and Environment, Chalmers University of Technology, Göteborg.

Gunnarsson, I., 2009. Interview with Ingemar Gunnarsson, Project leader GoBiGas Göteborg Energy, Göteborg, 2009-01-16.

Hansson, J., 2009. Perspectives on Future Bioenergy Use and Trade in a European Policy Context. Doctoral Thesis, Department of Energy and Environment, Chalmers University of Technology, Göteborg.

Hellsmark, H., Jacobsson, S., 2009. Opportunities for and limits to academics as system builders—the case of realizing the potential of gasified biomass in Austria. Energy Policy 37, 5597–5611.

Hellsmark, H., 2011. Unfolding the Formative Phase of Gasified Biomass in the European Union—The Role of System Builders in Realising the Potential of

---

[37] A challenge to be handled in a bridging policy is to secure long term feedstock contracts in order to demonstrate the economic viability of the projects to financiers.

Second-generation Transportation Fuels from Biomass. Doctoral Thesis, Department of Energy and Environment, Chalmers University of Technology, Göteborg.

Higman, C., van der Burgt, M., 2003. Gasification. Elsevier Science, Burlington.

Higman, C., van der Burgt, M., 2008. Gasification. Gulf Professional Publishing, Burlington, USA.

IEA, 2008. World Energy Outlook. International Energy Agency, Paris.

IEA, 2009. World Energy Outlook. International Energy Agency, Paris.

IES JRC, 2007. Well-to-Wheels Analysis of Future Automotive Fuels and Power trains in the European Context. The Institute for Environment and Sustainability of the Joint Research Centre, Ispra.

Jacobsson, S., Bergek, A., Finon, D., Lauber, V., Mitchell, C., Toke, D., Verbruggen, A., 2009. EU renewable energy support policy: faith or facts? Energy Policy 37, 2143–2146.

Jokela, V., 2008. Interview with Veikko Jokela. Research Advisor Chemical Pulping and Biorefining Stora Enso, Imatra, 2008-08-22.

Kåberger, T., 2009. Lecture on the Development of the Biomass Potential in Sweden and Europe, Zhejiang University. Hangzhou, China, 2009-11-16.

Leible, L., Kälber, S., Kappler, G., Lange, S., Nieke, E., Furniss, B. 2007. Fischer–Tropsch synfuels from cereal straw via fast pyrolysis and gasification—cost and benefits. Paper read at 15th European Biomass Conference & Exhibition, 7–11 May, at Berlin, Germany.

McKeough, P., Kurkela, E., 2008. Process Evaluations and Design Studies in the UCG Project 2004–2007. Research Notes 2434. VTT, Espoo.

Naab, P., 2008. Interview with Peter Naab, Energieversorgung Filstal, Göppingen, 2008-09-10.

Neij, L., 1997. Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology. Energy Policy 25, 1099–1107.

Olleros, F.-J., 1986. Emerging industries and the burnout of pioneers. Journal of Product Innovation Management 3, 5–18.

Palonen, J., 2008. Interview with Juha Palonen. Product Manager Gasifiers, Helsinki, 2008-03-27.

RENEW, 2008. Renewable Fuels for advanced Powertrains SYNCOM Forschungs- und Entwicklungsberatung GmbH, Ganderkesee, Germany.

Rosenberg, N., 1996. Uncertainty and technological change. In: Landau, R., Taylor, T., Wright, G. (Eds.), The Mosaic of Economic Growth. Stanford University Press, Stanford, California, pp. 334–355.

Rudberg, J., 2008. Interview with Jonas Rudberg, CEO Chemrec, Stockholm, 2008-12-03.

Rudloff, M., 2008. Interview with Matthias Rudloff, Commercialization Manager at Choren. Freiberg, 2008-01-30.

Sandén, B.A., Azar, C., 2005. Near term technology policies for long-term climate targets: economy wide versus technology specific approaches. Energy Policy 33, 1557–1576.

Salo, K., 2008. Interview with Kari Salo. CEO at Carbona, Helsinki, 2008-03-26.

Sohlström, H., Helin, M., 2008. Interview with Hans Sohlström and Maiju Helin. Executive Vice President and Specialist at the Division of New Business and Biofuels, UPM, Helsinki, 2008-08-19.

Specht, M., Zuberbühler, U., 2007. Interview with Michael Specht and Ulrich Zuberbühler at ZSW, Stuttgart, 2007-10-24.

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge.

Swedish Energy Agency, 2007. Pressmedelande 2007-12-14: Förgasningsprojekt i Värnamo läggs i malpåse—nya alternativ ska undersökas. Swedish Energy Agency, Eskilstuna.

Swedish Energy Agency, 2008. Utlysning: Intresseanmälan för demonstration och kommersialisering av andra generationens drivmedel och annan energiteknik. Dnr: 410-2008-003385. Eskilstuna.

Sydkraft, 1997. Värnamoverket—Uppförande och driftsättning 1991–1996 Sydkraft AB.

Sydkraft, 2000. Värnamoverket—Demonstrationsprogrammet 1996–2000. Sydkraft AB.

Thunman, H., Lind, F., Johnsson, F., 2008. Inventering av framtidens el- och värmeproduktionstekniker Elforsk rapport 08:79. Elforsk, Stockholm.

Thunman, H., 2009. Interview with Docent Henrik Thunman at the Department of Energy Technology. Chalmers University of Technology, Göteborg 2009-03-20.

Utterback, J.M., 1994. Mastering the Dynamics of Innovation: How Companies can Seize Opportunities in the Face of Technological Change. Harvard Business School Press, Boston.

Verbruggen, A., 2008. Windfalls and other profits. Energy Policy 36, 3249–3251.

Zwart, R., 2007. Large Scale Fischer-Tropsch Diesel Production, in: Proceedings of the Second International Freiberg Conference on IGCC & XtL Technologies, May 8–12, at Freiberg, Germany.

Zwart, R., Boerrigter, H., Deurwaarder, E.P., van der Meijden, C.M., van Paasen, S.V.B., 2006a. Production of Synthetic Natural Gas (SNG) from Biomass. Energy Research Centre of the Netherlands.

Zwart, R.W.R., Boerrigter, H., van der Drift, A., 2006b. The Impact of Biomass Pretreatment on the Feasibility of Overseas Biomass Conversion to Fischer–Tropsch Products. Energy and Fuels 20, 2192–2197.